Investigation into the Sinking of the I-90 Lacey V. Murrow Bridge

Contents

May 2,1991

The Honorable Booth Gardner
Governor
State of Washington
Olympia, WA 98504

Dear Governor Gardner:

On December 6, 1990, you appointed a Blue Ribbon Panel to investigate the sinking of the I-90 Lacey V. Murrow Bridge and charged its members with reassuring the public that the remaining bridges are safe and with determining the sequence of events leading to the sinking. With assistance from members of your staff and a forensic engineering consultant, we have completed our investigation and summarized our conclusions and recommendations in this report. We have also studied the more detailed technical report from the consultant and fully endorse that work, including the additional recommendations it contains.

At the outset we feel it important to say that we believe the remaining bridges are safe and well-maintained, so that the public can be reassured about using these important roadways. Our report focuses on special steps that should be taken if major reconstruction or rehabilitation of any of these bridges is needed, as well as practices and precautions that might be taken during inclement weather to assure the watertightness of these facilities. As we interpreted our charge, this assurance of continued public safety during normal bridge operations, and of additional precautions during extraordinary circumstances were of primary concern.

Our review has also focused on the practices and procedures in place during inclement weather and during the reconstruction and on the chain of events leading to the sinking of the I-90 Lacey V. Murrow Bridge. Our charge was not to assess liability, but to examine the possible causes of the sinking. Our finding is that, although the standard construction practices that were in place appear to have been in order, they did not adequately reflect the floating nature of this facility. We believe that this state's unique status as owner and operator of three of the four remaining floating bridges in the world, and the long-term effectiveness of these structures contributed to the apparent underestimation by both the State and the contractor of the risk of sinking. In summary, we found an absence of the type of construction practices or emergency response procedures that are commonly used on marine construction. It is to this end that we address the majority of our comments in this section of our report.

Our consultant's report narrows the probable cause of the sinking to the weight of excessive water in the pontoons, especially in the center pontoon (A-5), which initiated a chain reaction of pontoon sinkings. The report identifies two alternative scenarios of water accumulation, either of which is possible depending on the exact level of the bridge in the water the evening before it sank. Unfortunately, this status cannot be proven with available information. Further research does not appear warranted, however, in that it would be quite costly and would not substantially change our recommendations with regard to future actions on the remaining bridges. Whether the source of the water was from cracking of certain pontoons or from flooding in the sides of those pontoons, additional marine-oriented practices are warranted, as described in this report.

Thank you for the opportunity to serve as chair of the Blue Ribbon Panel.

Sincerely,

Aubrey Davis, Chair
I-90 Blue Ribbon Panel

Governor's Charge to the Panel

Introduction

The Public's Right to Answers

In creating the Blue Ribbon Panel to investigate the sinking of the I-90 Lacey V. Murrow Bridge, the Governor stated, "It's time for answers. The public has a right to know why this happened and what should be done to prevent the loss of another floating bridge." Other ongoing investigations are being conducted both by the State Attorney General on behalf of the Washington State Department of Transportation (WSDOT) and by the contractor, Traylor Brothers, Inc. The findings of these investigations are privileged, however, and much of what is known to the investigators might never be known to the public. In contrast, the work of the Blue Ribbon Panel has been conducted in public so that anyone interested might know what events led to the sinking and what can be done to prevent future occurrences.

The availability of the panel's report will:

- reassure the public that it is safe to travel on floating bridges;
- encourage the WSDOT to take actions to assure the safety of the remaining floating bridges themselves; and,
- assist the engineering and design community as it plans for construction or renovation of other floating bridges.

We commend the Governor for his action and point out that by reassuring the public, state decision-makers, and technical professionals of the intrinsic merit of floating bridges in transversing wide and deep bodies of water, the panel's findings may prevent unnecessary expenditure of public funds on future bridge construction.

Verbatim Charge

The verbatim text of the Governor's charge is reproduced below: *

Statement of Purpose:
The Lake Washington and Hood Canal floating bridges are unique assets to the State of Washington and are critical links in the state's transportation system. The recent (November 25, 1990) sinking of the old I-90 bridge and damage to the new I-90 bridge have raised many questions, including: What actually happened? Why did it happen? Is it safe to travel across these bridges? How can we assure that this doesn't happen again? Because these questions go unanswered, the public's confidence in the safety of the state's floating bridges has seriously eroded.

Therefore, the governor is creating a blue ribbon panel to conduct an independent investigation of the disaster. However, it is not the intention of this panel to determine legal issues or liability involved in the damage to the I-90 bridge.

Goals of the Independent Investigation:

- To assess the causes and consequences of the damage to the I-90 floating bridge; and
- To restore and ensure public confidence in the safety of Washington's floating bridges.

** The old I-90 Bridge is the same as the Lacey V. Murrow Bridge*

Governor's Charge to the Panel

Scope of the Panel's Investigation

- Investigate and report the chain of events leading up to the sinking of the old I-90 bridge and damage to the new I-90 bridge;
- Review Washington State Department of Transportation practices and precautions taken during inclement weather and construction activity on floating bridges;
- Examine public safety considerations on all floating bridges, especially during inclement weather and construction activity; and
- Determine likelihood of similar damage occurring in the future.

Recommendations to the Governor

Within three months of convening, the panel will report to the governor its findings and recommendations on:

- Determining the cause of the sinking of the old I-90 bridge;
- Preventing similar events in the future; and
- Developing a process by which the public may be kept informed of the safety of travel across the state's floating bridges.

Panel's Interpretation of Its Charge

In carrying out its charge, the panel has emphasized assuring public safety and the safety of the bridges themselves, and making recommendations that would preclude similar events in the future. We have been careful not to assess liability for the sinking. We have also not performed an in-depth investigation of ongoing operations, as it did not seem warranted based on our site visits. The panel chose not to evaluate the decision to reconstruct a new bridge in place of the old bridge, as it was thoroughly reviewed by a separate expert review group. Finally, we are not aware of specific plans for major reconstruction of any of the existing bridges, so that our comments in that regard are general.

The Panel's Approach to the Investigation

Public Meetings for Fact Gathering and Expert Testimony **Site Visits**

The panel has conducted its business in public, primarily through meetings at which we heard and questioned expert witnesses and considered written materials. We also conducted site visits to all the existing bridges and to the pontoons from the I-90 Lacey V. Murrow bridge that remain afloat.

Staff Assistance

We have received excellent staff assistance from Renee Montgelas and Tom Felnagle of the Governor's Office and Chris Gorley, a contract administrative assistant. The liaison function of these people was invaluable, and their advice as to policy matters was essential to our work.

We would also like to commend the WSDOT staff for its assistance in answering our many questions and providing us with written materials. They worked quite effectively within the limitations placed on them by the Attorney General's staff who wanted to protect their legal position should there be a law suit.

Contract with **Wiss, Janney, Elstner Associates, Inc.**

Early in our deliberation, we determined that we would need expert technical assistance, and sought proposals from nationally known forensic engineering firms. We selected Wiss, Janney, Elstner Associates, Inc., (WJE) and negotiated a scope of work that corresponded to the governor's charge to the panel. The WJE team was comprised of experts in bridge design and construction and marine engineering under the leadership of Dr. James R. C. Miller. They produced an excellent report under time pressures, constraints on available data due to possible litigation, and limited financial resources for the analyses required.

Our intention in retaining WJE was that we provide findings and conclusions at both technical and policy levels, with the consultant focusing on technical analysis and the panel focusing on policy analysis. Thus, our two reports are overlapping, but different. We include the Executive Summary and Conclusions sections of the consultant's report as appendices to this report, and note that there are many additional observations and recommendations about technical issues contained in the body of the consultant's report.

Findings and Recommendations

The panel presents its findings and recommendations in two parts: general findings and recommendations, and findings and recommendations specific to each task within our charge.

Endorsement of Consultant's Report

General Findings and Recommendations

In giving the panel its charge, the Governor said his goal is "to restore and ensure public confidence in the safety of Washington's floating bridges." We join with our technical consultant in stating that the public can travel across the State's floating bridges with confidence. We also feel that there is adequate monitoring of inclement weather conditions to assure bridge closures when needed, to prevent the public from using these crossings when such conditions make driving unsafe. For these reasons, our recommendations in this report are not directed at the safety of the traveling public, but at the safety of the bridges themselves, especially during the construction or reconstruction process.

We should also note that bridges, like all structures, are built to withstand certain natural forces, but that it is not economical with current knowledge to build for especially extreme conditions. This was true for the Hood Canal Bridge that sank under a force in excess of a "100 year" storm. While we recognize the economic loss and travel time inconvenience to users of that bridge, we do not question the need for such design limits.

Panel's Findings and Recommendations

Our recommendation related to this general conclusion speaks to the uniqueness and challenge of designing, constructing, operating, and maintaining three of the four remaining floating bridges in use in the world. That is, that four of the five floating bridges world-wide are in this state, including the Lacey V. Murrow Bridge. In fact, people come from all over the world to study our accomplishments, practices, and procedures. And, based on the long and successful history of these structures, including the fifty-year life of the Lacey V. Murrow Bridge, we are justly proud of our accomplishments.

It is, however, this pioneering spirit and our recognized successes that may have limited the WSDOT's evaluation of the possibility that the bridge might sink, and its advance planning for keeping the bridge afloat in the event that major leaks developed during construction. Nor did the WSDOT use external technical peer review familiar with marine practices who might have recommended such precautions. It is quite clear the construction of floating bridges involves marine construction practices that are not the same as road construction practices. Use of outside experts is especially needed for major reconstruction.

Findings and Recommendations

In fact, while there are few floating bridges worldwide, there are many floating structures and marine structure experts who might be consulted with regard to our facilities. Future reconstruction or major maintenance work would benefit from a comprehensive review by third parties with a fresh viewpoint.

■ *Recommendation:* Independent Third Party Review
Independent third party review should occur at several milestones of a reconstruction or major maintenance project by outside experts who have a variety of backgrounds. Design reviews, value engineering reviews, and constructability reviews should occur at the appropriate stage. Experts from within the WSDOT headquarters, district, and Marine Division should be involved. Also included should be outside experts who have floating bridge or floating structure background. Marine contractors should be involved. Recommendations from these experts should be incorporated into design and construction documents for the project.

An independent third party review group should also be tasked to review ongoing operations and maintenance and emergency preparedness to assure that appropriate marine standards are included in routine practices and procedures.

A second area of general concern has to do with actions that the WSDOT might take that exceed or reinforce standard construction practices. As will be evident in our specific recommendations, we do not find fault with the existing practices or with their apparent implementation in the Lacey V. Murrow Bridge reconstruction contract. Our belief is that the need to assure continued flotation of the bridges warrants additional measures and precautions, both before the contract is executed and during the reconstruction process. This is not a matter of determining liability; it is a matter of recognizing that, regardless of fault, the public will suffer significant economic and social costs if the bridge sinks.

The panel believes that the ongoing effectiveness of this facility, including fifty years of relative watertightness, and the relatively small scale of the bridge reconstruction compared to the larger I-90 construction project led decision-makers to adopt a standard highway design approach to the Lacey V. Murrow Bridge that did not adequately consider its unique nature and vulnerability to sinking.

The panel is aware of different project management approaches than that used on the Lacey V. Murrow Bridge project. Various parties involved in public works construction have developed contract procedures that involve full disclosure of all pertinent technical information; a proactive role by the owner and the designer to affect a "partnership" with the contractor during construction; a resource to solve problems and disputes equitably and responsively; and, a full evaluation of and plan for dealing with project risks.

■ *Recommendation:* Modified Contracting Approach
Review existing construction practices and procedures with a mind-set of "whatever it takes to keep the bridge afloat" and provide the extra contract requirements, information, permitting assistance, or surveillance to assure that this is the case. Make WSDOT's expertise in floating bridge design and construction available to the contractor through a "partnership" arrangement.

Findings and Recommendations **Specific to the Panel's Charge**

In addition to these general findings and recommendations, there are several areas of specific concern that are presented below by task as they relate to the panel's charge.

Task One

As we interpreted our charge, our first consideration was public safety on all floating bridges during inclement weather and construction activity. As stated above, our finding is that the bridges are as safe as our highways for travelers in most weather conditions, and that there are adequate precautions being taken during severe weather and construction to assure the safety of the traveling public.

■ *Recommendation:* None.
We refer to our general recommendations in this area, and to the more detailed discussion in the consultant's report.

Task Two

A second task was to "review Washington State Department of Transportation practices and precautions taken during inclement weather and construction activity on floating bridges." We asked our consultant also to review the practices and precautions of Traylor Brothers, Inc.; the results are contained in the consultant's report. Our general recommendation addressed a part of this task.
We have four specific findings as follows:

1. Considerations for evaluating any future proposals for reconstruction, rehabilitation, or heavy maintenance of floating bridges.
Our review found the normal contracting procedures to have been followed. Likewise, we found the practice of placing the burden for safe and effective construction on the contractor to be the standard practice. The shortcoming is not with these procedures or with their implementation; it is with the failure to take extra precautions because the structure being worked on was a floating structure. For example, in most marine construction there is extreme care to monitor and maintain the watertight status of the facility or vessel. This may involve automatic sensors, or round-the-clock surveillance;

it may include extra measures to seal openings resulting from construction; it may mean providing pumping/emergency staffing capabilities to rectify flooding before it leads to sinking. The purpose of these and other practices is to keep the structure afloat in all but the most extreme conditions.

■ *Recommendation:* Construction practices
Review the ongoing practices and procedures for assuring watertightness of the floating bridges, and assure that surveillance and response activities are aimed at precluding sinking. It is suggested that the contracts provide for marking and regular monitoring of the waterline; for watertight closures of temporary openings; for continuous automatic monitoring and documenting of water levels inside the pontoons, including interior cells; for full identification of flooding risks and contingency plans to mitigate these risks; and for specific emergency pumping requirements including pumping capacities, locations, reliable power sources, and staffing.

■ *Recommendation:* Prequalification of contractors
WSDOT has a standard prequalification procedure which looks to financial and overall project experience and capabilities. For future floating bridge projects, it is recommended that the WSDOT should take steps to assure that the successful contractor acquire specific marine expertise relating to assurance of watertightness before the project commences.

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2. Special requirements and contractual considerations for designing, constructing, operating, and maintaining floating structures, especially during inclement weather.
Inherent in the panel's charge is the issue of how the WSDOT deals with floating bridges during "inclement weather." This issue is best dealt with in three components: bridge operation under bad, but not severe weather; bridge operation under severe storms, and bridge protection during reconstruction or rehabilitation.

A. Bad weather
On the basis of personal inspections, interviews and observations, the panel believes that the day-to-day operation and routine maintenance of the floating bridges, even in bad weather, is commendable. The WSDOT clearly has in place a series of procedures which cause preventive maintenance activities to take place, for emergency procedures to be followed when weather conditions dictate, and for operational activities needed to keep traffic flowing in a safe and expeditious manner.

With regard to ongoing surveillance of the floating bridges, an electronic system to monitor water levels is warranted. Such a system would involve installation of level sensors in certain cells that would be connected to a central surveillance point for each bridge.

■ *Recommendation:* Electronic surveillance
Determine the appropriate design of an electronic cell monitoring system to monitor water level and implement such a system. Each bridge has unique cell arrangements, so it may not be necessary to instrument each cell.

Our concern with bridge inspection practices is that they are pre-scheduled so that advance preparation is possible that could mask deficiencies in ongoing practices, such as leaving hatches unbolted. We recognize that it is time-consuming and physically difficult to properly close all openings, and that without added emphasis on the need for watertightness, these and other practices might be overlooked or considered unimportant.

■ *Recommendation:* Independent random inspections
In addition to the scheduled major inspections, conduct random inspections by people not responsible for bridge maintenance in which the emphasis is placed on the watertightness of the bridge and the reliability of electrical and mechanical systems.

B. Severe weather
Establishing standards for bridge operations in severe weather is more difficult in that decisions as to closures must be made by skilled personnel on the basis of their experience in various weather conditions. We were impressed by the caliber, commitment, and experience of the people currently in positions of authority under these circumstances. Our concern is with the perpetuation of knowledge should these individuals retire or transfer to another location.

■ *Recommendation:* Staff continuity
Review the training procedures for such personnel and assure that there is adequate implementation and sufficient back-up on staff for continuity in all key positions.

A second concern is for the safety of travelers who might get caught on the bridge during severe weather. Current practice is to dispatch crews to close the bridge in severe weather conditions. The panel finds that mechanical devices might be more effective.

■ *Recommendation:* Automated bridge barricades
Study the most effective mechanical means to close the bridge when needed and implement these systems as practical.

C. Reconstruction or renovation
Reconstruction or renovation of floating bridges is the final area of investigation under this task. As stated in our general comments, we recognize that it is standard practice

for the state to designate the contractor as responsible for safe and effective construction practices. Here we are not commenting on liability of either party in the specific instance of the Lacey V. Murrow Bridge. Rather, we reiterate our concern that the WSDOT should make provisions for inspection and maintenance that exceed standard construction practices and reflect the floating nature of the bridges.

We are also aware of continued disagreements as to the implementation of the contract between the WSDOT and the contractor. As our consultant reports, some of these discrepancies are a matter of claims by the contractor. We do not intend to comment on the merit of those claims. Our concern is with the expeditious correction of deficiencies that might lead to flooding, regardless of which party must pay for such corrections.

■ *Recommendation:* **That the WSDOT, with help from outside marine construction experts, prepare a set of contractual provisions that establish minimum standards for ongoing surveillance, inspection, reporting, and immediate rectification of discrepancies that might lead to flooding of bridges during construction.**

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3. Inter- and intra-agency relationships, especially with regard to environmental requirements.

State law requires invitation for bid proposals for public constructions projects to set out when reasonably ascertainable regulations dealing with the prevention of environmental pollution. These do not appear to have been stipulated in the invitation to bid on the I-90 Lacey V. Murrow reconstruction project. It was, however, stipulated in the WSDOT contract with Traylor Brothers that the contractor would be responsible for acquiring needed permits and meeting all environmental regulations. We note that of all parties involved, only one unsuccessful bidder inquired of the Department of Ecology (DOE) in advance as to applicable requirements. We question the efficacy of waiting until the contract had been let to determine major permitting requirements, as was the effect of this procedure on this contract. The result was a serious delay in project start-up and significant claims by the contractor at the outset of the project. This delay later contributed to the hydrodemolition activity being on the critical path for project completion, and for continuing pressure on the contractor and WSDOT to step up the pace of work. These difficulties and the inability to monitor water levels while the hydrodemolition machines were operating could have led to excess water loading.

We believe that Department of Ecology (DOE) requirements with regard to the disposal of wastewater from hydrodemolition were known to members of the environmental staff within the WSDOT, yet they were not stated in the bid

documents. We also believe that the WSDOT environmental staff was not made aware of plans for hydrodemolition until late in the contracting process. This appears to be due to a breakdown in both intra- and interagency coordination. Had the requirements been clearly identified, costly and time-consuming delays in start-up might have been avoided.

During the course of its investigation, the panel received several informal comments regarding the WSDOT's inability to obtain timely legal advice on controversial differences between itself and the contractor. The panel was not able to fully investigate the comments; but feels that further investigation is warranted.

■ *Recommendation:* Full implementation of the interagency cooperation agreement between the WSDOT and the DOE; full involvement of WSDOT environmental staff. Reinforce the lines of communication between project staff and environmental staff members within the WSDOT, and review the existing interagency cooperation agreement to determine how it might be strengthened and fully implemented.

■ *Recommendation:* Advance environmental planning. Require contractor to demonstrate knowledge of environmental requirements when bidding. Conformance with environmental regulations is an essential element of a "partnership" contractual arrangement between the WSDOT and the contractor.

■ *Recommendation:* Outside legal counsel for major construction/reconstruction projects. Since rapid decisions are sometimes critically necessary, consider the assignment of outside contract counsel on major projects.

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4. WSDOT's disposition of the Arvid Grant report recommendations
The WSDOT acquired an expert appraisal of the condition of the I-90 Lacey V. Murrow Bridge and the feasibility of major reconstruction early in the design stage. It received a report from Arvid Grant and Associates, and responded formally to the recommendations in that report, adopting some and rejecting others. The only exception is the decision to work throughout the storm season which was not so documented. When the WSDOT adopted an Arvid Grant recommendation, it incorporated appropriate requirements in the reconstruction contract.
The problem is that those requirements were not fully implemented.

■ *Recommendation:* Contract enforcement
Assure that contract requirements that bear on bridge safety are fully implemented.

Findings and Recommendations

Task Three

A third task of the Panel was to "determine the likelihood of similar damage occurring in the future." Provided the recommended additions to construction and maintenance practices are implemented, and that the future design and implementation of floating bridge reconstruction incorporates marine construction procedures and practices, it is unlikely that similar damage would occur in the future.

The panel's consultant has identified "once in a lifetime" sort of events, including major (100-year) storms, major collisions by a ship, or earthquakes of extreme magnitude, as factors that might result in the loss of a bridge. As explained above, we do not recommend changing design and construction standards to account for these extreme circumstances. The WSDOT upgrades its bridges to current seismic standards during a major reconstruction project. Both the Third Lake Washington Bridge and the new section of the Hood Canal Bridge are designed in such a way as to maintain flotation following a collision which would flood a number of cells in a pontoon.

■ *Recommendation:* None

Task Four

Our final charge was "to investigate the chain of events leading up to the sinking of the old I-90 Bridge and damage to the new bridge." Through extensive interviews with WSDOT staff and more limited interviews with representatives from Traylor Brothers, viewing videotapes, reviewing paperwork related to inspections and claims on the project, and conducting laboratory analyses and computer simulations, our consultants have created a probable sequence of events leading up to the sinking of the Lacey V. Murrow Bridge. It appears clear from their work that the sinking of the bridge was triggered by a massive accumulation of water in the center pontoon of the bridge (Pontoon A-5), the weight of which caused the bridge to sink.

The lowering of the bridge in the water due to the weight of excess water accumulated in the pontoons was a key link in the chain of events leading to the sinking. In their report to us, the consultants offer an opinion "that the bridge was lost when water entered into several pontoons through the open holes cut in the side walls to acco mmodate the installation of watertight doors and through the door frames, none of which had yet received a watertight door. Had these holes in the pontoons been tightly covered and contingency planning performed to monitor the pontoons for leaks with reaction forces and pumps available, we believe the leakage in the pontoons which led to the sinking could have been controlled." (p. 88)

A number of factors contributed to the lowering of the bridge in the water prior to Saturday night, November 24 including gradual water accumulation in the cells from rain and hydrodemolition, additional accumulation from waves and runoff related to

the 30 hour storm at Thanksgiving, leaks through cracks, and leaks through equalizer holes and open interior watertight doors during hydrodemolition. The question is what was the major source of that water? One theory had been that the splicing in the rebar failed during the storm. However, a test conducted at the University of Washington indicated that the splices had adequate strength to prevent premature cracking. If the splices were not especially weak, then large amounts of water within the pontoons coupled with storm induced forces would be needed to cause cracking sufficient to sink the bridge. Calculations show that the weight of water loading had to be large and was not likely to have resulted from rain water alone. Rain water must have combined with wave water which entered through holes in the sidewalls and decks and with water accumulated during hydrodemolition work on Pontoon A-5, which took place in September.

Nowhere in the advanced planning and design work was there an analysis of the effect of combining loading from hydrodemolition water being stored in the pontoons and additional water buildup from storms with loads created by storm forces. Such forces would have resulted from storms that occurred during the September hydrodemolition work. The likely effect of the combined stresses from the storms and accumulated water would be to open cracks or widen pre-existing cracks, such that the bridge was in a weakened, but still floating, position during the pre-Thanksgiving period. The extended storm of November 21 through 24, with its additional water loading potential, sustained winds and waves, might have caused additional crack widening and resultant water inflow that went undetected in the inspections that occurred just prior to the sinking.

As we offer this summary and the more complete consultant's report as to the probable causes of the sinking, we are cognizant of our instruction not to suggest liability for the sinking. It is clear that our findings could become a matter of contention between the state and Traylor Brothers, Inc., either through the claims adjudication process with the WSDOT or through litigation. The Attorney General has instructed the WSDOT as to its disclosures to us, as has the attorney for Traylor Brothers limited their participation in our investigation. We understand the legal reasons for this reticence, but found it to be an impediment, nevertheless. We also feel it important to commend the helpfulness of the WSDOT in assembling information and providing us extensive background briefings. WSDOT staff members did all that was possible to assist us within the limits placed on them by the Attorney General. Both the WSDOT and Traylor Brothers, Inc. were helpful in supplying certain videotape information of the actual November 25, 1990 event and diver-taken footage secured as each party was compiling a record of events.

Findings and Recommendations

Our direct involvement with the consultant's work makes us confident of the conclusions he reached as to the causes of the sinking. What we find extremely disconcerting is the fact that the exact level of the bridge in the water is not known, and that such knowledge is necessary to determine with certainty the cause of sinking. What concerns us is the lack of practices and procedures that would have made this information available, not just for finding fault after the fact, but, far more importantly, to ensure timely reaction to pontoon flooding that would have prevented the sinking. To quote the consultant, "The principles of good marine practice were not a specific contract requirement, nor were they followed on this project. While everyone must have understood that a floating bridge could sink, the thought that a sinking was a real risk must have been remote" (p. 53).

To reinforce this point, the panel calls attention to the "emergency situation" that occurred on November 8th in which water flooded into the pontoon through side openings, and water had to be pumped from the pontoon directly into the lake to rectify the situation. The panel is aware of repeated unsuccessful efforts by the WSDOT to cause the contractor to cover the side openings. However, we concur in the consultant's conclusion that, even this situation and the "increased awareness of potential water accumulation hazards did not result in actions to seal the holes in the side to prevent water entry. WSDOT could at any time have taken action to seal the holes (with its own forces or other contractor forces, if necessary). The fact that the holes were not sealed suggests that the holes were not viewed as a serious threat to the flotation of the pontoons" (p. 52).

Within the scope and budget of his assignment, our consultant has successfully completed his assignment. In fact, the question of why the bridge sank may never be answered definitively because of lack of exact documentation of the external waterline. The Panel considered recommending additional experiments on the remaining pontoons; however, such tests would be very costly, would entail a slight risk of sinking the remaining portions of the bridge, and would have little impact on future activities related to floating bridge design, construction, operation, or maintenance.
We do not recommend the conduct of such tests.

We recognize that it might be frustrating to some members of the public that we cannot be more precise; however we feel that the real public value of our endeavor is in satisfying our first three tasks of reassuring the public that it is safe to travel on the remaining floating bridges and of recommending future practices, especially during inclement weather and construction, that would assure that the bridges remain afloat.

EXECUTIVE SUMMARY

The Lacey V. Murrow Bridge sank on November 25, 1990 while undergoing renovation. This bridge was one of the four floating bridges in Washington State. A Blue Ribbon Panel appointed by Governor Booth Gardner engaged Wiss, Janney, Elstner Associates, Inc. (WJE) to investigate the chain of events that led to the sinking, review practices and precautions taken during construction and inclement weather at the Murrow Bridge and other floating bridges within the state, examine public safety questions, and evaluate the likelihood of similar damage in the future.

WJE formed a multi-disciplined team which included persons skilled in structural analysis, bridge engineering, contract construction management, marine architecture and construction, materials science, and risk analysis. The team conducted its work by review of documents and video tapes, interviews, on-site visits, engineering review, calculation and analysis, and physical testing of bridge materials. Information obtained by the team was unsworn, provided primarily by the Washington State Department of Transportation (WSDOT) and Traylor Brothers, Inc., the contractor who was working on renovating the bridge when it sank. WJE's investigation was limited in time and resources by its contract.

At the time the bridge sank, a large number of holes had been made in the north side of the bridge pontoons near the waterline, as part of the construction work. The actual location of the waterline was not recorded. The contractor's personnel accompanied by a WSDOT inspector had pumped water out of a number of cells within the bridge's pontoons on November 24 and left the bridge around 6:00 pm feeling everything was in good order. The bridge sank at about 9:30 am the next day.

Witnesses and videotapes indicate that flooding of the A5 pontoon in the center of the bridge initiated a chain reaction of pontoon sinkings. WJE has concluded that if the freeboard attributed to the bridge on November 24 were correct, then the most likely cause of the bridge

sinking was widening of cracks in the center region of Pontoon A5, leading in short time to uncontrollable water entry through the multiple holes in the north side of the pontoons. If the freeboard were lower than the witnesses remembered, water also may have entered through the holes in the side or around the edges of plywood partially covering the holes. The mechanism for the development and widening of cracks involves water accumulation in the pontoons which could have increased stresses in the bottom slabs during storms in October and November, and a region of weakness in Pontoon A5 (as well as others) where reinforcing bars were lapped. Pontoon A5, when it sank, is believed to have broken apart in such an area of lapped reinforcing.

The contractor was using a hydrodemolition process to remove sections of the pontoons. The holes made in the pontoons were not covered effectively to prevent water entry. During the course of the construction work, a gradual build-up of water in the pontoons probably occurred as a result the hydrodemolition process, rain, and lake splash water accumulation. A long storm which included a period of thirty hours of winds in the 30-35 mph range accompanied by heavy rain added more water to the bridge and imposed dynamic forces on the bridge which may have contributed to the widening of existing cracks, particularly in the region where bars were spliced. This storm ended on November 24.

The accumulation of large amounts of water in the pontoons was not anticipated in planning the construction, nor was the contractor authorized to store water in more than four cells under each of four hydrodemolition machines. There were almost 2200 cells in the 22 bridge pontoons. There was no provision for systematic inspection of cells for water throughout the bridge. Inspection initially was concentrated on the areas where the contractor was working. After the third and fourth hydrodemolition machines were added in October and November, WSDOT began to place more emphasis on checking water levels, but there were no records to show that anyone had precise knowledge of where water was accumulating throughout the bridge (i.e. a periodic report which showed cell by cell water levels).

No preparations were made to detect and react promptly to sinking of the bridge. The contractor was required to have pumps on site. The total pumping capacity was unspecified. By the time flooding was recognized on Sunday morning, the available workers and equipment were found inadequate to save the bridge. The contractor had little or no experience in construction of floating structures and the WSDOT personnel, who may have been involved with the design and construction of other floating bridges, and had little or no specific marine engineering, naval architecture, or marine construction background. There appeared to be a general lack of appreciation of the risks involved in allowing water to accumulate in the pontoons and of the consequences of reducing the effective freeboard of the pontoons by multiple openings in the sides. The contractor and WSDOT employees appear to have considered the risk of sinking small and as a consequence that risk was not fully evaluated. The practices and precautions taken during inclement weather and construction did not focus on the prevention of flooding of compartments and were not adequate to prevent the sinking.

After reviewing the designs of the other three floating bridges within the State of Washington and performing on-site visits, it is concluded that the bridges are safe for public use provided they continue to receive adequate inspection and maintenance. The bridges appear to be in good condition. Their designs follow accepted engineering practice.

Several recommendations are made to reduce the risk of loss or damage to floating bridges in the future. The most significant need is to provide a means to detect pontoon flooding as soon as it may occur for any reason. Once flooding is detected, effective measures to restore the watertight integrity of a pontoon as rapidly as practical must be available. Obviously, during construction work, the same watertight integrity should be maintained as established during normal operation of the bridges, or extra precautions should be taken during construction to cope with potential flooding.

The risk to the public in using the floating bridges in inclement weather is not considered substantially different from using any of the State's major highways in the Seattle area, or from

the potential for a catastrophic event to any highway bridge structure. Extremely severe storms, such as the 100 year frequency storm, are threatening to all the floating bridges as well as other structures. If past traffic control practices are followed there is little likelihood that people will be on the bridges during such an extreme weather event. If the pontoons are not allowed to flood during a 100 year storm, the chance of bridge survival will be materially increased.

CONCLUSIONS

We formed a number of conclusions in performing our work for the Governor's Blue Ribbon Panel. Our conclusions are organized in two groups. The first addresses the sinking of the Lacey V. Murrow Bridge; the second, the three bridges that remain in service over the Hood Canal and Lake Washington.

CONCLUSIONS REGARDING THE SINKING OF THE MURROW BRIDGE

1. The process of conceiving the renovation project; investigating its feasibility; design; preparation of plans, specifications, and estimates; advertising for bids; and awarding the contract appears to have been typical of the process successfully used on other projects administered by the Washington State Department of Transportation. The process, in general, is adequate for contract construction if significant aspects of the proposed construction are fully evaluated and understood prior to contract award. There must be equal understanding by the staff which administers the contract after the award. In the case of the Murrow Bridge renovation we note below certain aspects which apparently were not fully evaluated and/or understood.

2. The Washington State Department of Ecology's role was to monitor for possible violations of the state's water quality regulations and to give advice or interpretation of the regulations. Neither WSDOT, nor Traylor fully recognized the impact of the environmental regulations that would apply to the hydrodemolition work in Lake Washington until after the award of the contract. This lack of knowledge led to delays which are still a subject for resolution under the terms of the contract. The delays could have contributed to the sinking by putting additional pressure on WSDOT and Traylor to meet the scheduled completion date, since missing that date would delay other I-90 construction projects.

3. The level of experience and knowledge concerning work on marine floating structures of the persons in both the Traylor project organization and WSDOT was apparently insufficient to foresee sinking as a significant risk. The contractor, particularly, appeared to lack an appreciation of the risks involved in allowing water to accumulate in the pontoons and of the consequences of reducing the effective freeboard of the pontoons by multiple openings in the sides.

4. There was no effective effort to monitor the water level of the bridge or detect flooding of pontoon cells, nor to maintain watertight integrity within the cells which contained watertight doors. There were no contingency plans to deal with flooding, nor to provide extra equipment and manpower to deal with flooding. The bridge was usually left untended during Sundays and holidays. These factors contributed to the loss of the bridge on Sunday, November 25.

5. Flooding of the A5 pontoon in the center of the bridge over the evening of November 24 and the morning of November 25 initiated a chain reaction of pontoon sinkings which resulted in the loss of the bridge. If the freeboard attributed to the bridge on November 24 were correct, then the most likely cause of the bridge sinking was widening of cracks in the center region of Pontoon A5,

leading in short time to uncontrollable water entry through the multiple holes in the north side of the pontoons. If the freeboard were lower than the witnesses remembered, water also may have entered through holes in the side of the pontoons or around the edges of plywood partially covering the holes.

6. The mechanism for the development and widening of cracks involves water accumulation in the pontoons which could have increased stresses in the bottom slabs during storms in September through November, and a region of weakness in the bottom slab of Pontoon A5 (as well as others) where reinforcing bars were lapped. Pontoon A5, when it sank, is believed to have broken apart in such an area of lapped reinforcing. We consider that cracking sufficient to cause the sinking would not have occurred if water accumulation in a single pontoon were limited to the "5.5 feet in 4 cells" criteria established for hydrodemolition.

7. The contractor was using a hydrodemolition process to remove sections of the pontoons. The holes made in the pontoons were not covered effectively to prevent water entry. During the course of the construction work, a gradual build-up of water in the pontoons probably occurred as a result the hydrodemolition process, rain, and lake splash water accumulation. A long storm which included a period of thirty hours of winds in the 30-35 mph range accompanied by heavy rain added more water to the bridge and imposed dynamic forces on the bridge which may have contributed to the widening of existing cracks, particularly in the region where bars were spliced.

8. The anchorage system of the Third Lake Washington Bridge was damaged by sinking pontoons from the Murrow Bridge. However, we do not conclude that the decision to site the newer bridge next to the Murrow Bridge was necessarily flawed. We understand the siting decision underwent extensive public and private review, including litigation. We believe that the risk of sinking can be

made acceptably small in performing construction at parallel bridges if adequate precautions are taken.

CONCLUSIONS REGARDING THE THREE INSERVICE FLOATING BRIDGES

1. We believe the three floating bridges are as safe to use as the major highways that bring traffic to the bridges. Traffic accidents rather than bridge failure are the most likely cause of death or injury to the public.
2. The bridges appear to be in good condition and adequately maintained.
3. The risk of sudden, unexpected sinking is very remote. In the event of a major leak in one or more pontoons, we believe there would be more than adequate time to evacuate the bridge providing the loss of flotation is detected before major flooding of multiple compartments occurs. Even with a major leak, the bridge should survive if compartmentation is maintained and action is taken to seal the leak and remove the water. Compartmentation is less extensive in the Evergreen Point Bridge and the older section of the Hood Canal Bridge than in the newer section of the Hood Canal Bridge and the Third Lake Washington Bridge. Re-examination of compartmentation design is recommended.
4. The bridges will remain safe to use through their nominal design life and beyond provided they are maintained and operated properly.
5. Proper maintenance includes a detailed program of inspection which identifies potential structural problems and assures early attention to their correction, and appropriate attention to mechanical and electrical systems.
6. Proper operation requires that continuous individual and management attention is given to assuring that the bridges maintain their flotation. This means that positive measures are taken to assure that watertight hatches and doors are

sealed at all times when compartments are unmanned. It also includes provision for detection of flooding and for immediate and effective response should any compartment become flooded. Proper operation also requires continuing review of traffic warning and control systems for adequacy.

7. Special care must be taken when the bridges undergo renovation in the future to carefully analyze the risks imposed during construction and to take precautions to overcome such risks. The risk of flooding is always present. The risk may be made very small by enforcing specific safeguards during construction.

8. We believe that rehabilitation work on bridge pontoons may be performed in the future without loss of a bridge if good marine practice is followed regarding maintenance of flotation. This would include around the clock surveillance and preplanning to quickly react to emergency situations.